

NOBEL PRIZES IN SCIENCE 2023

AN APPRECIATION

S T Lakshmikumar

This is an attempt to appreciate the science which has been recognized and rewarded with Nobel prizes in Chemistry, Physics and Medicine for the year 2023, an annual effort on my part for the past many years.



Katalin Karikó and Drew Weissman

We begin with the Nobel Prize in Physiology or Medicine which was awarded to Katalin Karikó and Drew Weissman “for their discoveries concerning nucleoside base modifications that enabled the development of effective mRNA vaccines against COVID-19.”

The global havoc caused by the COVID pandemic in the last few years, the millions of deaths, the lockdowns by governments to try and control the spread of the pandemic as well as the resultant economic misery for those least equipped to withstand it are very fresh in everyone's mind. One point about the award has to be stressed. The prize has NOT BEEN awarded for the COVID vaccines. Vaccines developed using the established non mRNA vaccine techniques had a significant role in containing the pandemic. The specific work highlighted by the award committee was performed by the laureates in 2005, well before the pandemic. The development of vaccines has validated the mRNA platform as a completely new addition to the human repertoire of medical approaches to fight disease and death. To properly appreciate the new approach, it is necessary to briefly recapitulate some basic concepts of biology.

Diseases are caused either by the malfunction of one or more parts of the living organism or by external agents like bacteria and viruses. As will be described later, the mRNA platform can potentially help in both cases. The immune system, when functioning properly, detects the presence of these external agents and destroys them. It also retains a memory of organisms that had attacked earlier. This ensures that the body is better equipped to withstand any subsequent attack. Vaccination provides this advantage without the risk of permanent disability or death in the first attack itself.

However, this acquired capability of the immune system cannot be passed on to succeeding generations. But many other capabilities needed by the organism to survive are passed on through genes (DNA). The DNA has the "information" which is used to make the proteins. The body including the immune system is made of proteins. mRNA is the intermediary between DNA and proteins.

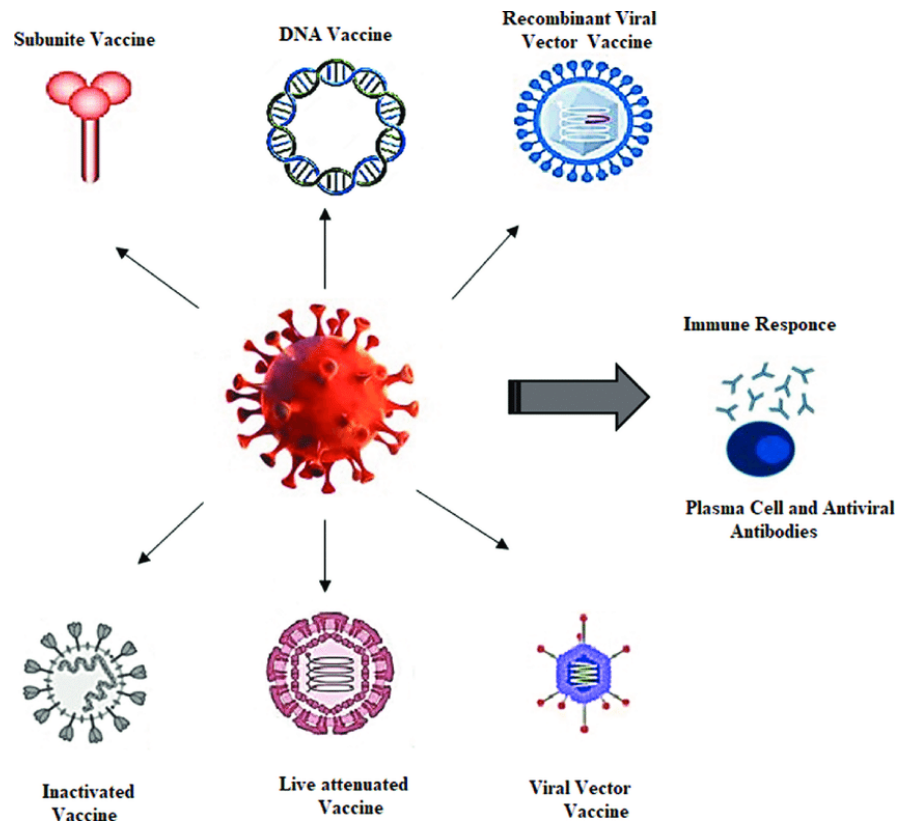


Fig. Different types of vaccines

Let us consider the difference between the mRNA platform and earlier approaches to vaccination. That will also reveal why this versatile method has potential applications beyond vaccine development. The very first vaccine created protection against smallpox by deliberately causing cowpox, a harmless mild disease. The virus causing cowpox is an attenuated vaccine that was available in nature. For other diseases, the attenuation has to be achieved by human ingenuity. The MMR vaccine used today is an attenuated virus vaccine. For other diseases, it becomes necessary to use a killed disease causing organism as the vaccine. Hepatitis A vaccine is a good example. Some vaccines are directed against the toxin created by the germ, for example tetanus. In some cases, it is possible to present parts of the germ, which may also require genetic engineering to create immunity. Hepatitis-B is a vaccine of this type. The most recent approach, the viral vector vaccine uses modern genetic engineering to alter a harmless virus causing, for example, the common cold to create immunity for a serious disease. Some vaccines protect for the whole life and others only for a year or two.

Not every one of the above methods works with every disease. Moreover, the procedure for developing and manufacturing a vaccine is unique to that disease. The germs causing the disease may mutate or change quite rapidly making the vaccine ineffective and the whole process of development may have to be repeated. Quite often the manufacturing process is extremely complex and costly. Vaccination against seasonal flu is a good example where the vaccine used has to be altered almost every year.

It is quite obvious that using the protein making ability of the body with the genes from the germs will be a very attractive vaccination strategy. In particular, adjusting for the mutation of germs may be extremely easy. The devil as they say is in the detail.

First and foremost, how to produce the genetic material in sufficient quantities for commercial vaccines and how to prevent their degradation? RNA in particular is extremely unstable. Secondly, how to ensure that the material enters the cells? The cells of the immune system can recognise and respond to the presence of conventional vaccines in the intercellular fluids but this will not work with genetic vaccines. In case DNA is used as a vaccine, it has to cross both the cell wall and the nuclear membrane. These barriers normally permit only small molecules like glucose to cross, not long genetic polymers. These are in addition to the normal impediments to medical treatments, efficacy and side effects.

The first of these issues was resolved when the molecules that perform the transcription from mRNA to protein were cloned and the process of producing multiple copies of any desired mRNA was optimised. The first success in transferring mRNA to cells was reported by encasing the unstable molecule in liposome vesicles. Subsequently a cationic lipid DOTMA and later an improved version lipofectin were synthesised in order to trap the negatively charged nucleic acids and deliver them across the negatively charged cell membranes. Lipofectin was found unsuitable for use in humans because of adverse reactions but newer combinations of cationic lipids were discovered to solve this problem.

Kariko and Weissman built their work on this foundation. They sought ways of optimising protein delivery in tissues and organs using the mRNA platform so that clinical trials could begin for a variety of applications. Weissman's expertise in immunology complimented Kariko's background in RNA biochemistry and this synergy led to several important insights. Weissman's target was to find a vaccine for HIV infection and the two scientists demonstrated that mRNA encoding the HIV-1 structural protein, Gag, stimulated primary T cell responses in dendritic cells in cell cultures.

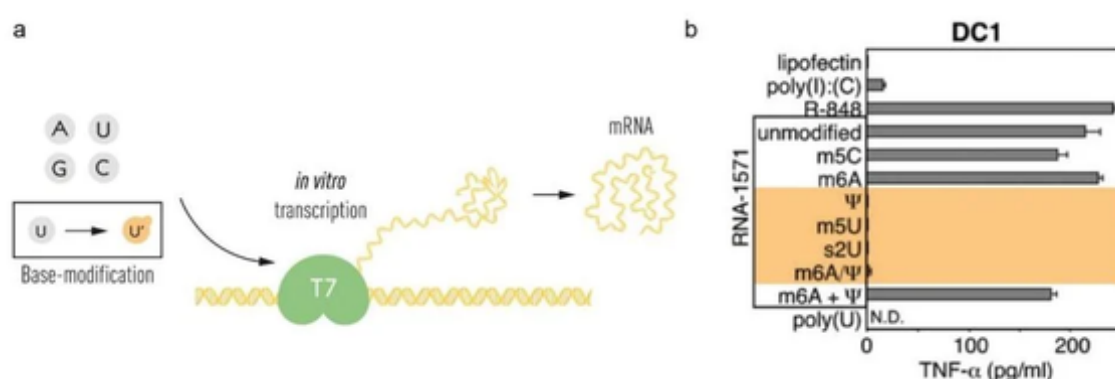


Fig. Results highlighted show the absence of inflammatory reaction in some modified mRNAs

A major problem with therapeutic use of mRNA was inflammatory reaction in the human body. A key insight came about when Karikó focused on why **transfer RNA** (tRNA), used as a **control** in an experiment, did not provoke the same immune reaction as mRNA. Karikó and Weissman determined that a specific nucleoside modification in mRNA, replacing **uridine** with **pseudouridine** made the

mRNA platform suitable for clinical use. This is the work mentioned in the citation of the Nobel prize. They also worked on the development of an improved drug delivery vehicle based on the cationic lipid particles for mRNA.

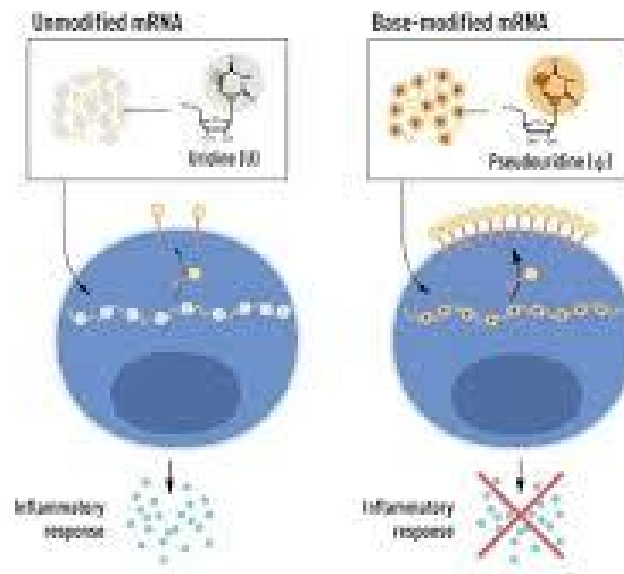
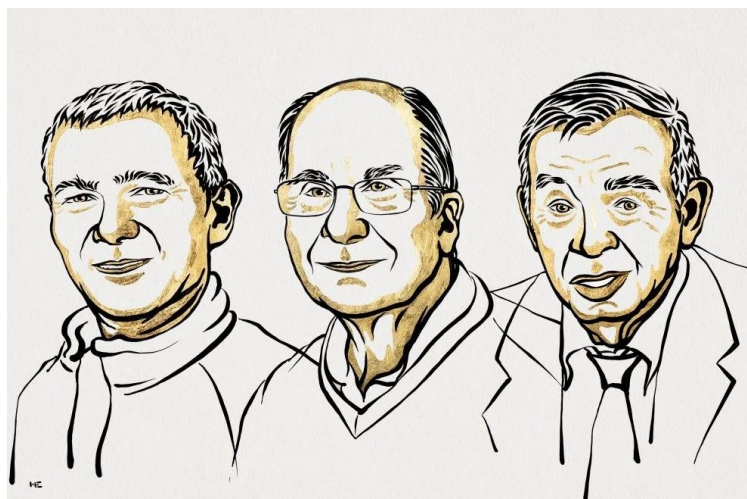


Fig. Modified RNA results in higher protein yield

They then demonstrated that in addition to stopping inflammatory response, the modification leads to the creation of more protein making the process significantly more effective and useful. Karikó, Weissman and colleagues further demonstrated that in vitro transcribed mRNA activates protein kinase R (PKR), an anti-viral protein that protects cells from invading pathogens. The pharma company, BioNTech founded in 2008 and Moderna, founded in 2010 bought the rights of the patents issued to Karikó, Weissman and the university of Pennsylvania to develop personalized cancer vaccines and to use the mRNA platform to reprogram somatic cells to pluripotent cells and deliver therapeutic proteins, for example to repair damaged tissue. Pre-clinical results of mRNA-based Zika virus vaccines that used modified bases were reported by Norbert Pardi and Weissman in 2017 and Moderna announced the start of a clinical trial against Zika virus as well as two phase I clinical trials to evaluate the safety and their vaccine against influenza virus H10N8 and H7N9, two avian influenza strains with pandemic potential. They also started research on the development of an mRNA-based vaccine against Middle East Respiratory Syndrome (MERS-CoV). It was this experience that permitted Pfizer/BioNTech and Moderna to use the highresolution structure of the SARS-CoV-2 spike published in record time by Jason McLellan's group in early 2020 to start the work on their COVID vaccines in which this year's nobdl laureates had a minor role if any. Incidentally, Jason McLellan's work was extremely useful for all the other COVID vaccine developers too.

In the wake of the COVID pandemic, governments had released massive financial grants for the development of vaccines. Even more importantly the medical regulatory authorities in the advanced countries relaxed some of their very stringent guidelines on clinical trials which were intended to ensure that the risks for the volunteers in trials and the recepients were as low as humanly possible. The governments even shielded the commercial companies from of any claims for damages in courts. These measures brought forward the recognition of the contribution by this year's laureates in opening a new frontier in medical treatment. in of cancer, cardiovascular and metabolic diseases and ischemia in addition to development of new vaccines



Mounqi Bawendi, Louis Brus and Aleksey Yekimov

The Nobel Prize in Chemistry 2023 was awarded to Mounqi Bawendi, Louis Brus and Aleksey Yekimov “for the discovery and synthesis of quantum dots.” Anyone teaching quantum mechanics in a college begins with a simple idealised concept called a “particle in a box”. A quantum dot is the closest real object to the “particle in a box”. However, a caveat is in order. Every force of nature other than gravity is a quantum force. So, as Richard Feynman so correctly emphasised, everything in our experience that does not involve gravity is a quantum phenomenon and while something is called a quantum dot, there are no “non-quantum dots”. A particle in a box is a very simplified concept. There is just a particle confined to a region in space. No properties of the particle or of the box are taken into account. But this simple concept leads not only to the idea of quantum states, energy levels that the particle is permitted to have, that there are corresponding to these levels, regions of space where there is a higher probability for the particle to be detected and finally to a mathematical relationship between the difference between energy levels and the size of the box. It is the last of these that is relevant for the nomenclature of quantum dots. Quantum dots are simply physical systems in which it is possible to notice the change in energy levels with the size. Given that it has been possible to calculate certain experimentally measurable quantities to the tenth decimal place and the calculations agree with the measurements to that accuracy, equivalent to independently measuring and calculating the diameter of a sphere of the size of earth to an accuracy of the thickness of a human hair, the fact that experimentally one is able to confirm the variation of energy levels in quantum dots with size is *passee*. It is almost an equivalent of another verification of the law of conservation of energy.

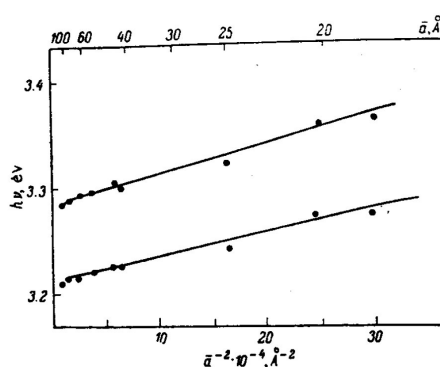


Fig. Variation of CuCl exciton energy (y axis) with particle size (top x axis) and theory (bottom y axis)

Alexey Yekimov is credited with being the first to attribute observations made in a real system to quantum size effects. He added copper and chlorine to silicate glasses in excess of solubility. On heat treatment nanocrystals of copperchloride precipitated out of the glass. The average size was determined by small angle x ray scattering and the energy of the optical exciton lines of CuCl were shown to change with particle size matching theoretical predictions.

Given that the x-ray scattering results provide only an average particle size, and the process of thermal annealing cannot directly ensure particle size uniformity, the match between experiment and theory in Yekimov's results is rather surprising. Yekimov, in his discussion, explicitly draws attention to earlier studies in thin films which were also attributed to quantum size dependence. A brief description of these thin film results is quite useful at this point.

Molecular-beam epitaxy (MBE) in ultra-high vacuum, used enabled the deposition of high-quality semiconducting thin films and made it possible to optically resolve multiple quantum states in for example thin (< 5 nm) GaAs quantum wells formed between AlGaAs layers, after selective chemical etching to remove the GaAs substrate. Theoretical understanding of the role of Coulomb interaction (exciton effects) in low-dimensional structures such as quantum wells was also well established by the early 1980s. More importantly these structures had become extremely useful in high speed optoelectronic devices. This highlighted a feature of quantum dots most important for practical applications. While the bandgap of a bulk semiconductor is fixed, that of a quantum dot varies with size.

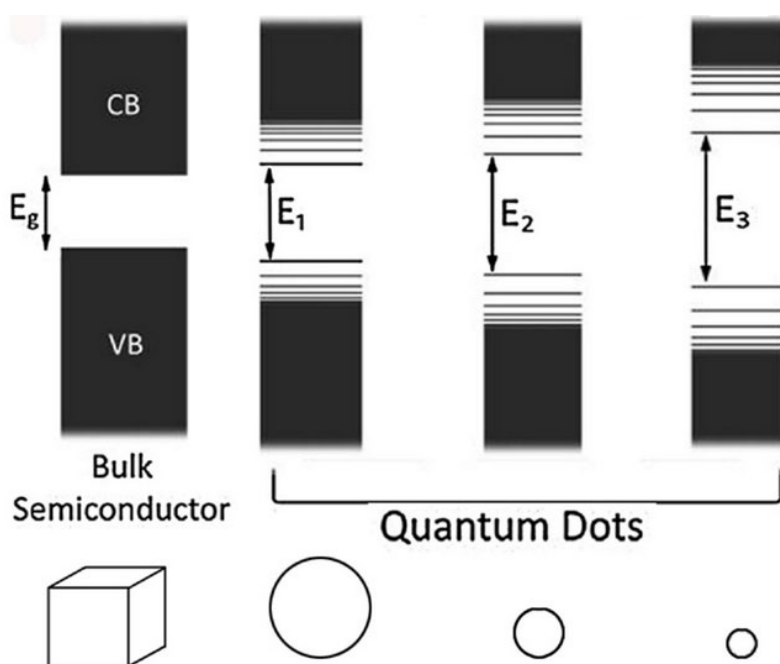


Fig. Variation of semiconductor band gap in quantum dots

The variation of bandgap and as a corollary of the physicochemical properties motivated research into the possibility of fabricating semiconductor particles of a single precisely controlled size in large quantities through chemical methods. The epitaxial thin-film methods of fabrication are extremely capital intensive requiring sophisticated equipment. The first to successfully make such particles and also demonstrate quantum size induced changes was Louis Brus. It is important to remember that use of such nanoparticles was known even since antiquity. The most famous example is the Lycurgus cup,

a two thousand year old Roman art piece. It looks green in reflected light but red in transmission. The curious phenomenon could only be understood in recent years after the nano quantum dot revolution. Many other research perplexing results of the previous period were also recently reattributed to quantum size effects.

Colloidal crystallites of CdS, ZnO, and TiO₂ were being investigated in the 1970s for potential photocatalysis application because the energy levels were suitable. Brus and co workers prepared relatively small CdS particles in solution in the presence of a styrene/maleic anhydride copolymer that helped prevent coagulation and flocculation. This method of preparing nanoparticle colloids was already known. The freshly prepared colloid showed a narrow size distribution around 4.5 nm, however, ageing for as little as one day caused the crystallites to dissolve and recrystallize to form larger particles with a broader size distribution around 12.5 nm, a process known as Ostwald ripening. Brus and coworkers demonstrated that the bandgap of the aged nanoparticles was equal to that of bulk CdS while the bandgap of the freshly prepared particles was blue shifted as expected from quantum size effects. From the references included in their work of that period, it is clear that Brus, like Yekimov, was directly influenced by the results from epitaxial nanostructures. Brus was not even aware of the earlier work by Yekimov. Both Brus and Yekimov refined the theory of quantum size effects by adding material relevant attributes and electron hole interactions. The discovery of quantum size effects in colloidal nanocrystals was more successful in stimulating research efforts as compared to the work on CuCl in glass. However, progress was hampered by limited homogeneity and quality of the available nanocrystals, with variations in size, shape, crystallinity and surface electronic defects.

Research and application of quantum dots really took off in a big way following the demonstration by Moungi Bawendi and co-workers in 1993 that quantum dots with much more well-defined size and with high optical quality could be produced. Their synthesis begins with the injection and immediate pyrolysis of organometallic reagents (the precursors for the desired nanoparticles) into a hot coordinating solvent with a high boiling point. The rapid increase of reagent concentrations results in abrupt supersaturation and in nucleation that takes place at a well-defined moment. Injection is accompanied by a sudden drop in temperature and dilution of the precursors such that growth stops. After reheating to the desired growth temperature, a slow growth and annealing process takes place in the coordinating solvent that helps to stabilise the resulting colloidal dispersion.

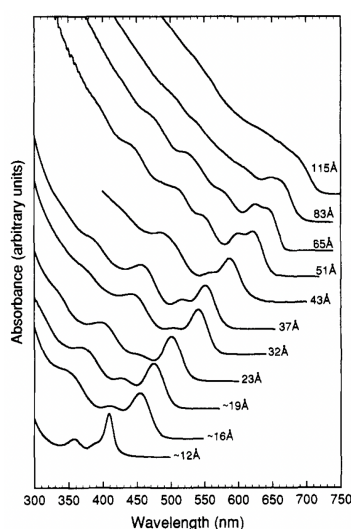


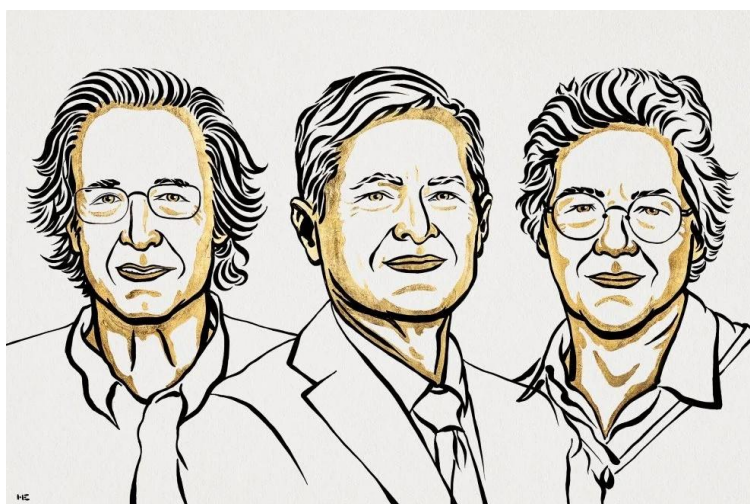
Fig Room-temperature optical absorption spectra of CdSe nanocrystallites dispersed in hexane and ranging in size from ~12 to 115 Å.

Particles can be selected using purification and size dependent precipitation. The result is macroscopic quantities of nanoparticles with regular core structure and shape, with consistent surface derivation and electronically passivated semiconductor surface, and with a well-defined size that is determined by dynamic temperature control during the growth phase. Relatively sharp optical absorption and emission spectra were observed at room temperature, with a luminescence quantum yield up to 10%. By removing aliquots during the growth process, an entire series of particle sizes can be obtained during a single growth run.

This principle of temporally discrete nucleation followed by controlled growth was known from the production of monodisperse lyophobic colloids for more than 40 years. The use of the hot-injection synthesis by Bawendi and co-workers led to an adaptable and reproducible chemical strategy for synthesising monodisperse nanoparticles using a wide range of material systems. It opened the door to the development of large-scale applications of quantum dots.

The optical quality of colloidal quantum dots was enhanced by the development of core-shell quantum dots that consist of a wide-bandgap shell, such as ZnS, to confine electrons and holes to a small-bandgap core (such as CdSe). In this way, the charge carriers in the core were separated from surface states, such as unsaturated bonds, that are detrimental to optical performance. Adding such an additional layer in the same reaction became possible by modifying the hot injection synthesis method, avoiding size-selective precipitation and achieving near monodisperse nanocrystal synthesis. Synthesis of water-soluble quantum dots with high optical quality made integration of inorganic quantum dots with biological systems possible.

Application areas of quantum dots include use in photovoltaics, other forms of energy conversion, photodetectors, biomedical imaging, nanomedicine, and generally in infrared technology, where quantum dots may give access to bandgap ranges not easily accessible with other materials. An important consideration is the toxicity of some quantum dots and their precursor materials. Environmental and health effects of quantum dots have been however an area of concern as perhaps should be the proliferation of extremely unreliable research in the area.



Pierre Agostini, Ferenc Krausz and Anne L'Huillier

We finally take up the most esoteric of this year's prizes, the Nobel Prize in Physics 2023 which was awarded to Pierre Agostini, Ferenc Krausz and Anne L'Huillier "for experimental methods that generate attosecond pulses of light for the study of electron dynamics in matter".

This work reexamines the interaction between an electron in an atom with one or more photons. The situation when the electron interacts with a single photon has been completely understood for more than a century. When the energy of the photon is equal to the energy difference between two quantum levels in the atom, the photon is absorbed. This results in the Fraunhofer lines observed in 1814 and explained by the Bohr model of the hydrogen developed in 1913. If the energy of the photon does not match a difference in energy levels, it is not absorbed. However, if the energy is large enough, the electron is knocked out of the atom. The minimum energy required for this "photoelectric effect" is called the work function and excess energy if any of the photon will be equal to the kinetic energy of the photoelectron. This was the theory developed by Albert Einstein in 1905, the work for which he was awarded the Nobel prize. With familiar light sources, the intensity is low enough for this assumption that only one photon is available to an electron is valid. Because of the observation of Fraunhofer lines, one can note that this is true even on the surface of the sun where the radiation is $\sim 10^7 \text{W/m}^2$.

With the development of femtosecond lasers, we now have sources of light that have an intensity as high as $\sim 10^{16} \text{W/m}^2$. When atoms are illuminated with this radiation multiple photons are available for each electron, during the duration of the pulse. The energy acquired by the electron is obviously very high and one would expect the photoelectron to emerge with very high velocities. But there is a further complication. The light intensity is a very short pulse and the intensity is reduced back to zero in a few femtoseconds. The electron does not escape from the attraction of the ion, the atom that had lost the electron. As the electron returns to one of the quantum states in the atom, it loses the kinetic energy in the form of a photon. An electron that had originally gained n photons will release a single photon of energy $nh\nu$ where $h\nu$ is the energy of each photon in the laser pulse ($\nu = c/\lambda$, λ is the wavelength of the laser radiation).

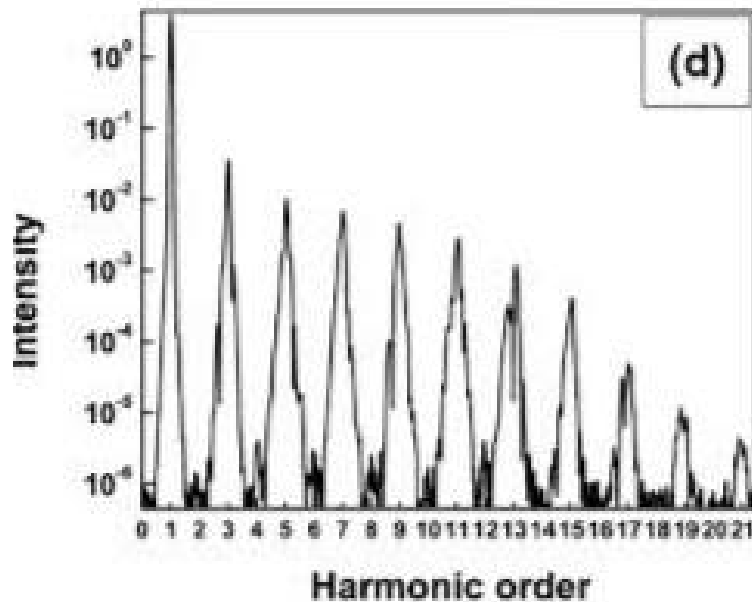


Fig. Decreasing intensity of higher harmonics in HHG

Even though multiple photons are available, the probability of the electron absorbing $n+1$ photons is lower than that of absorbing n photons. So atoms irradiated by these high power femtosecond pulses should be expected to generate pulses of light at higher harmonics. This is called higher harmonic generation or HHG and the intensities of higher orders should

decrease as shown in figure above. In some cases, due to reasons of symmetry only odd harmonics are present. But that is a matter of detail.

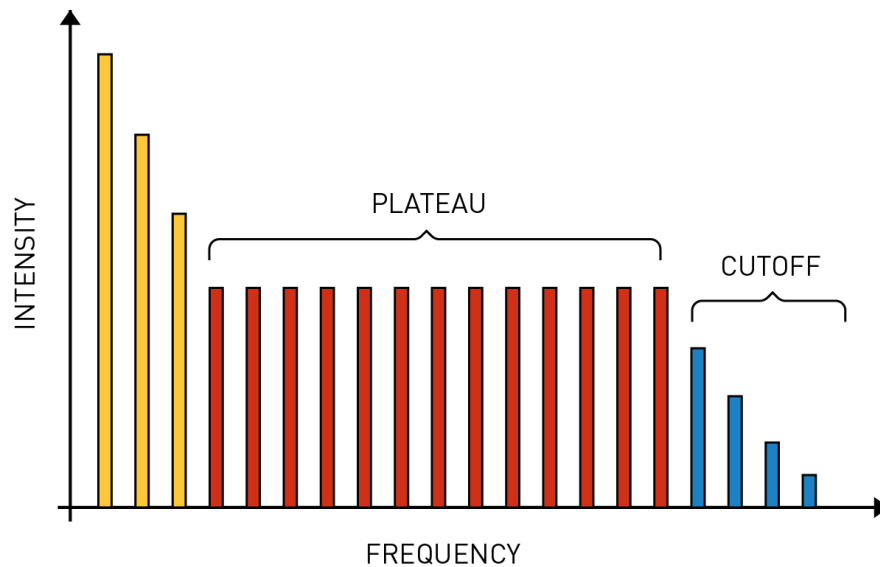


Fig. Intensities in higher harmonics generation showed a broad plateau rather than decreasing

An experiment performed using infrared photons [1064 nm] high power laser at a research centre in Paris-Saclay in France by L'Huillier and co-workers gave very surprising results. The emission intensity of the odd harmonics first decreased rather sharply, then were essentially constant from the 5th harmonic up to about the 33rd harmonic for argon, and then decreased again. Fourier analysis shows that wider the frequency spectrum, shorter the pulse in time domain and vice versa. The plateau would correspond to a very narrow pulse, in the deep ultraviolet, possibly only several tens of attoseconds wide. The question remained as to what physical process was responsible for the formation of the plateau and how it could be exploited.

L'Huillier and co workers solved this puzzle of the plateau, initially through a numerical solution of the time dependent Schrodinger equation in 1991 and a quantum field theoretical description in 1994. This explained both the observed plateau as well as the reason why such a plateau was not observed in earlier studies that used lower wavelength (248 nm) lasers. Quantum mechanical tunnelling is central to the description but a quasi classical description in the language treating the photons as electromagnetic waves makes it possible to visualise the process.

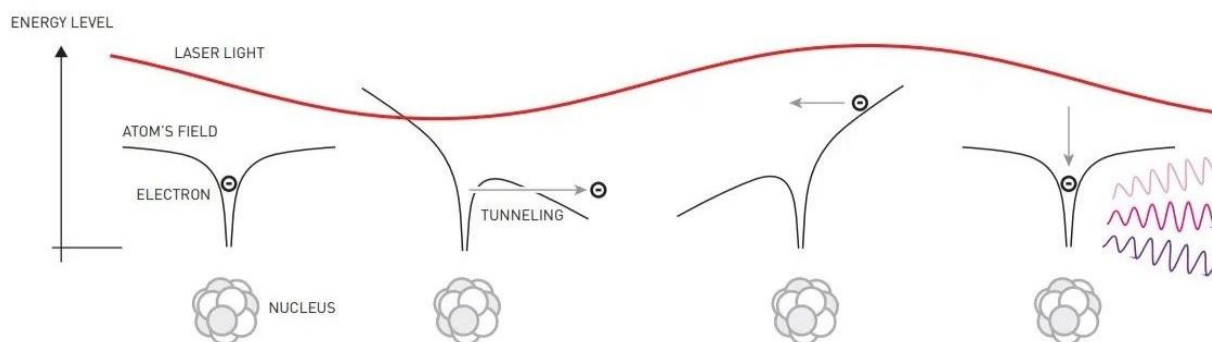


Fig. Semi classical description of HHG with plateau

In the rescattering, or three-step semiclassical model of HHG, first, the laser field causes tunnelling ionisation. In the second step, the laser field accelerates the electron. When the field reverses in the next half-cycle, the free electron may return back to the ion and recombine. In the third step, the recombination process converts the kinetic energy of the electron to an emitted extreme ultraviolet (XUV) photon. The electron is forced by the 248-nm laser radiation to return to the ion much faster than at 1064 nm. The possibilities for the electron with consequent lower kinetic energy to develop a HHG plateau are more limited. This theoretical understanding clearly pointed to an attosecond pulse being created but confirming this experimentally looked very unlikely, since even movement of electrons between atoms takes several femtoseconds. The difference between HHG and HHG with the plateau is attributed to tunnelling but the difference cannot be visualised beyond this qualitative statement. One has to rely only on the veracity of the detailed theoretical, mathematical model.

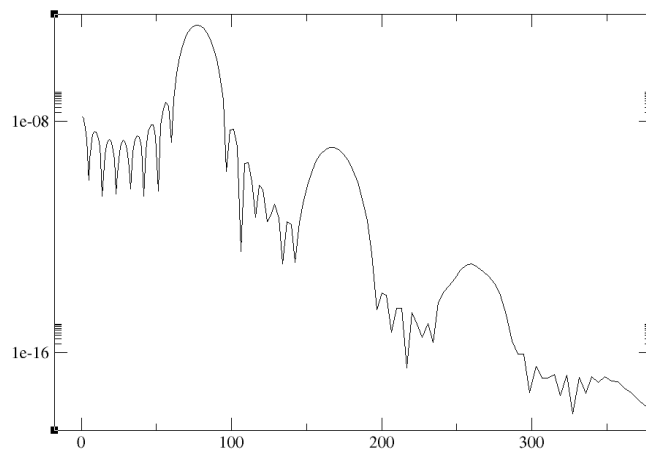


Fig. Variation of the number of photoelectrons emitted with energy

The first step in the direction of confirming the formation of attosecond pulses was taken by Pierre Agostini in 1979, even before the discovery of HHG with the plateau. He identified a phenomenon called Above Threshold Ionisation ATI. This is the emission of photoelectrons with extremely energetic photons. A simpleminded application of Einstein's idea would predict that the photoelectron would emerge with much higher velocities possibly comparable with the velocity of light and hence relativistic correction may be necessary. But in reality the variation of the number of photoelectrons emitted with energy shows a large number of complex features as shown in the figure above.

Having developed a complete theoretical understanding of this spectrum, Pierre Agostini devised in 1994 a technique of indirectly determining the width of the optical pulse emerging from the HHG with the plateau experiment. The technique focuses the XUV pulse and light from the drive laser onto a rare gas target and analyses the photoelectrons emerging from the target as a function of the delay introduced to the pulse train of the drive laser. A refined version of this is now called RABBITT, (reconstruction of attosecond beating by the interference of two-photon transitions). One should remember that the XUV pulses were themselves produced by the interaction of the drive laser pulses with an inert gas. But in the second exposure photoelectrons rather than light are detected. So while the experiment appears to use an inert gas for the second time, what is being investigated is the

interaction of the drive pulses with the electrons emitted from inert gas atoms rather than interaction with atoms. As with the distinction between HHG and HHG with the plateau mentioned above, the attosecond width of the XUV pulse can only be confirmed after sophisticated calculations. In Paris-Saclay, at the same research centre where HHG with the plateau was discovered, the Agostini group produced a train of pulses with a duration of 250 attoseconds, using argon as the target gas and the RABBIT metrology. In Vienna, the group lead by Ferenc Krausz simultaneously reported producing isolated pulses of 650 attoseconds width with a slightly different experimental set up and Krypton as the target gas. Using the value of the pulse width obtained in the first experiment, it is possible to use the same experimental procedure to observe the movement of electrons in atoms at the attosecond time frame.

For example, is the emission of a photoelectron instantaneous? If not, is there a difference between the time required for a photoelectron to emerge from an s orbital and a p orbital? The laureates experimentally provided an answer to this question. The Krausz's group found that when the neon atom is ionised by 100-eV photons, the 2p electron takes 21 attoseconds more to leave the neon atom than the 2s electron. But, a theoretical calculation showed that the value should be lower by a factor of two.

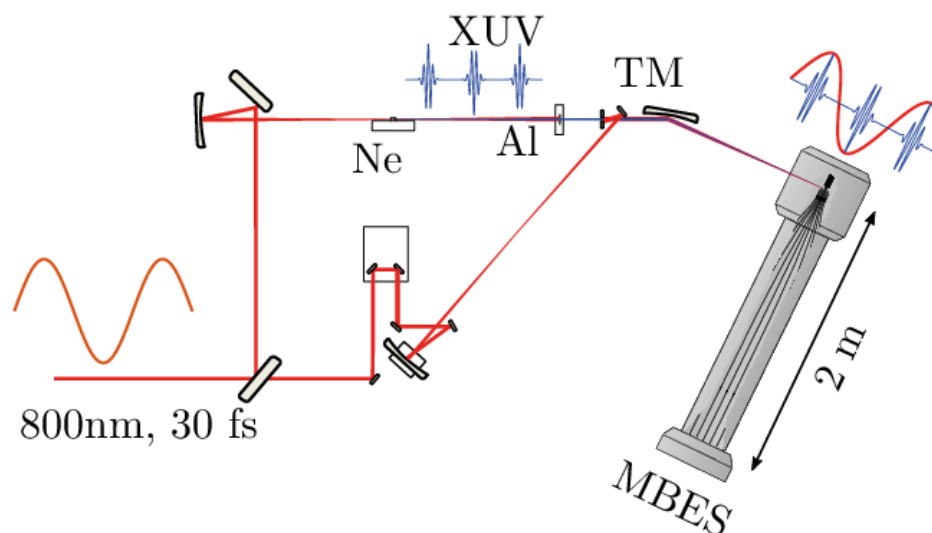


Figure 3. Schematic illustration of the experiment performed by L'Huillier in Lund using RABBIT

Using the experimental facility schematically shown above, L'Huillier and co workers obtained results that agreed with the theory and also identified the reason for the discrepancy. The drive laser at 800 nm, 30 femtosecond (fs), is sent into two different arms by a beam splitter. High harmonic generation (HHG) in a gas jet of neon gives a train of XUV attosecond pulses. The IR pulses from the drive laser and the XUV pulses (typically with a 10–20 eV bandwidth) are overlapped and focused by a toroidal mirror on the neon gas target. The XUV photons ionise the target gas, and the photoelectrons are analysed by a magnetic bottle spectrometer.

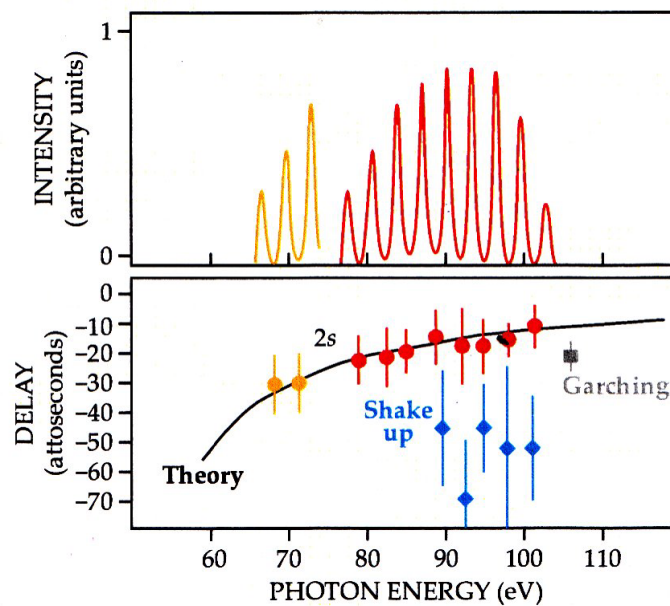


Fig. The results of L'Huillier and co workers compared with theoretical models and the earlier result of Krausz's group

In the upper part, the HHG spectrum used in the experiment is shown. The negative time delays for ionisation of 2p with respect to 2s are shown as yellow and red dots. The result from Krausz group in Garching is shown as a square. There is excellent agreement between the Lund experiment and many body perturbation theory. The first result from the Krausz group gave a different result because the interference from a single photon removing an electron from 2p while at the same time promoting another 2p electron to the 3p subshell could not be avoided. This is marked as "shakeup" in the figure.

These results have resulted in extensive studies of light-matter interaction in the attosecond time domain, examining molecules, liquids and solids. Attosecond spectroscopy is expected to reveal a plethora of complex electron interactions in charge transfer, charge screening, image charge creation, electron-electron scattering, and collective electronic motion. The ability to shake the electrons in pump-probe experiments and to study the response on attosecond timescales may offer tremendous opportunities to explore completely new physical phenomena. However that may pan out, the studies are interesting and intriguing in what they reveal about the basic nature of physics itself.

Eugene Wigner made a very thought provoking statement about the relationship between physics, mathematics and reality. "The miracle of the appropriateness of the language of mathematics for the formulation of the laws of physics is a wonderful gift, which we neither understand nor deserve." Leaving aside the subjective nature of deserving, the beauty of the present results is that the "appropriateness" has now been experimentally tested right down to an attosecond. Fourier analysis of light pulses seems to be working right up to that time scale. The studies push the envelope of our current quantum theory with a classical approximation down to the attosecond. The idea of complementarity that often is viewed as philosophical rambling by Neils Bohr is turns out to be useful to visualise tunnelling of an electron and its subsequent acceleration by an electric field. The beauty that the experiments performed by this year's physics laureates revealed far excels any mundane utility of these techniques in the future.

Science is acclaimed as an objective understanding of reality. Selecting a work for recognition and reward is seldom. Over the past fifteen years, while making these presentations of the current year's Nobel Prizes in science, I have made my share of subjective comments on the awards. Nevertheless, my usual conclusion that Scientific understanding creates happiness even in absence of creativity stands. One can excuse one's own lack of personal contribution by noting that the creator needs an appreciative audience and hopefully the present attempt does succeed in creating in the readers an appreciation of the Nobel Prizes in Science for 2023.